Comparison of Human Haptic Size Discrimination Performance in Real and Simulated Environments

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Abstract

The performance levels of human subjects in size discrimination experiments in both real and virtual environments are presented. The virtual environments are displayed with a Phantom desktop three degree-of-freedom haptic interface. Results indicate that performance of the size discrimination tasks in the virtual environment is comparable to that in the real environment, implying that the haptic device does a good job of simulating reality for these tasks. Additionally, performance in the virtual environment was measured at below maximum machine performance levels for two machine parameters. The tabulated scores for the perception tasks in a sub-optimal virtual environment were found to be comparable to that in the real environment, supporting previous claims that haptic interface hardware may be able to convey, for these perceptual tasks, sufficient perceptual information to the user with relatively low levels of machine quality in terms of the following parameters: maximum endpoint force and maximum virtual surface stiffness. Results are comparable to those found for similar experiments conducted with other haptic interface hardware, further supporting this claim.

1 Introduction

This paper presents a comparison of human haptic performance in real and virtual environments. Results support the case that haptic interfaces are good at simulating real objects, and indicate that they can do so without excessive machine performance demands for the tasks described here. Comparisons of performance in real and virtual environments have been made in the past. Typically these comparisons are made with the virtual environment display operating such that the best achievable representation of reality is presented to the user. For example, completion times for a pick and place task performed in a real-world control environment and in three virtual conditions were presented by Richard et al. [1]. Their findings showed that for the pick and place task, completion times, a measure of task performance, were lower for the real-world control environment than for each of the three virtual environments tested. However, accuracy for depth and lateral placement were comparable for one haptic display and the real-world control. Similarly, Buttolo et al. [2] used comparative methods to study the differences in performance of simple manipulation tasks with real objects, with a virtual reality simulation containing force feedback, and remotely with a master and slave system, also with force feedback. Their findings also showed that performance with the virtual environment was similar to that with real objects. This paper takes a similar comparative approach to verify the quality of a haptic device in simulating realistic virtual environments for a simple perceptual task of size discrimination, where subjects determine which of two objects placed side by side is larger. Additionally, the quality of the haptic device, in terms of two parameters, is degraded and another performance comparison is made.

2 Methods

2.1 Virtual Environment Apparatus

The Phantom desktop was used to simulate the virtual environments. Hardware specifications are listed in Table 1.

Table 1. Phantom Desktop hardware specifications

Workspace	16x13x13 cm
Maximum force	6.4 N
Maximum continuous force	1.7 N
Force feedback	3 DOF
Position sensing	6 DOF

2.2 Testing Environments

In both the real and virtual environments, subjects held a stylus with the dominant hand and entered responses on a computer keyboard with the non-dominant hand. The dominant hand was shielded from view with a curtain for both tests. A frame for the curtain was constructed from a cardboard box. The face closest to the subject was cut out and replaced with a curtain to

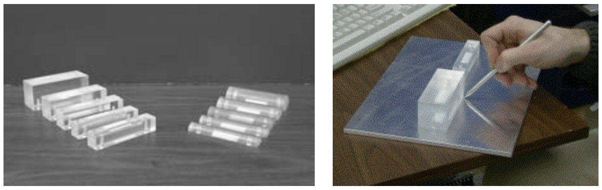

Figure 1. Photograph of the real blocks and the environment for a square ridge size discrimination task.

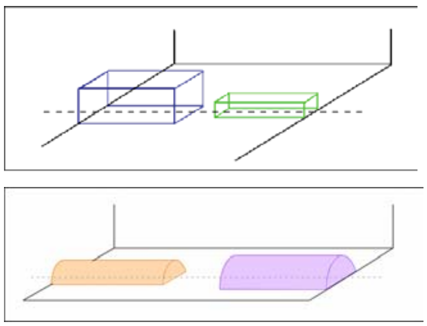

Figure 2. 3-D model of the simulated environment for the square and round ridge size discrimination tasks

Figure 3. Test subject seated at testing station for virtual environment experiments. (The box and curtain used to obstruct the subject's view are removed in this picture)

allow free movement of the hand. The back of the box was also removed to allow the test administrator to change blocks for the real environment. The box was secured to the desktop throughout the practice and testing sessions.

2.2.1 Real Environment

The real environment consisted of square and round cross-section blocks, machined out of acrylic, mounted on pegs on an aluminum plate. The blocks were covered with clear contact paper to account for any texture irregularities due to machining. The subject used an aluminum stylus to explore the environment. These blocks and the test plate are shown in Figure 1.

2.2.2 Virtual Environment

Square and round cross-section blocks were displayed haptically with the Phantom Desktop. Figure 2 shows a visual representation of the virtual environment. Subjects explored the environment with the Phantom stylus as shown in Figure 3.

2.3 Experimental Paradigms

Perception experiments were conducted for ridges of square and semicircular cross-sections, and were conducted in a real environment and several virtual environments (high fidelity, low fidelity-force, and low fidelity-stiffness). The order of testing was varied for each subject to ensure that learning effects were not a factor. Short practice sessions (10 trials each) were conducted prior to each experiment.

2.4 Subjects

Ten test subjects were used for the size discrimination experiments. A cross-section of subject types (gender, dominant handedness, and experience with haptic devices) was chosen for each of these experiments.

2.5 Procedures

In each experiment, the subject was asked to feel the exterior of the two ridges and determine which was larger, entering their response on the keyboard (left or right). One of the two ridges was always the base size, with an edge length of 20 mm. The second ridge had an edge length of 20, 22.5, 25, or 30 mm. In both the real and virtual environment experiments, twenty trials of each stimulus pair were presented to the subject. In all, subjects sat for eight test sessions of eighty trials which were each preceded by a ten trial practice session.

2.5.1 Machine Parameters

In order to create low-fidelity environments, two machine parameters were selected to describe haptic interface machine performance, namely maximum force output and time delay. Force output correlates to torque output limits of motors, and increased torque output requirements are typically proportional to motor cost and size. Time delays are unfavorable in a real-time system, and reduction of time delay usually requires faster computing speed and higher quality electronics, each coupled to an increase in price. These two quantifiable machine parameters are easily understood by designers and are typical measures of system quality. During experimentation in the low-fidelity virtual environments, these machine parameters were lowered to minimum levels for good performance of the size discrimination task as determined by O'Malley and Goldfarb [3, 4]. To limit the force output of the manipulator, the output command force was saturated at 4 N for each trial [3]. This was accomplished by creating new classes in GhostSDK called WeakCube and WeakCylinder that take the maximum output force as an input. These classes were based upon the GstCube and GstCylinder classes in GhostSDK. For the stiffness low fidelity simulations, k was set to 450 N/m and b to 45 Ns/m as recommended in [4].

2.5.2 Experiments

Experiment 1 – Real

Testing was conducted with the acrylic blocks and aluminum stylus for both square (A) and round (B) cross-section ridges.

Experiment 2 – High-Fidelity Virtual

Testing was conducted with the Phantom Desktop at default values for force and stiffness. Tests were conducted for both square (A) and round (B) cross-section ridges.

Experiment 3 – Low-Fidelity Virtual: Force

Testing was conducted with the Phantom Desktop at the default value for stiffness and a maximum output force of 4 N. Tests were conducted for both square (A) and round (B) cross-section ridges.

Experiment 4 – Low-Fidelity Virtual: Stiffness

Testing was conducted with the Phantom Desktop at the default value for force and a virtual surface stiffness of 470 N/m. Tests were conducted for both square (A) and round (B) cross-section ridges.

3 Results

Results for all experiments are presented in Figures 4 (square cross-section ridges, all environments) and 5 (round cross-section ridges, all environments). Results are shown as percent correct scores and are the average results across all test subjects. Standard errors are shown with error bars.

4 Discussion

In Figure 4, we see that performance in the high fidelity virtual environment is comparable to that in both low-fidelity virtual environments for size discrimination of ridges with square cross-section. At a size difference of 1.25 mm, performance is best in the real environment, although this result is not significant as determined by an analysis of variance (ANOVA). At all other sizes, performance in the real environment is comparable to that in the high and low fidelity environments.

Figure 5 shows results for all round cross-section size discrimination experiments. Again, we see comparable performance between the high and low fidelity virtual environments at all size differences. At the 1.25 and 2.5 mm size differences, performance appears to be slightly better in the real environment,

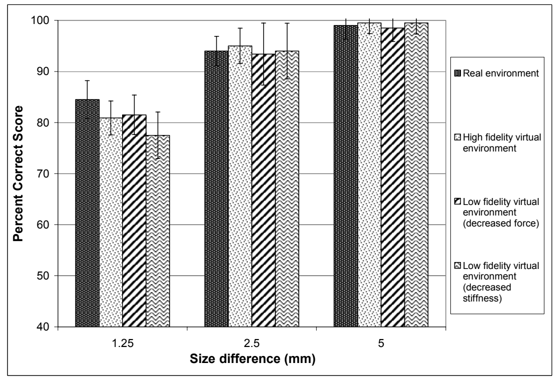

Figure 4. Results for all size discrimination experiments with square cross-section ridges (1A, 2A, 3A, and 4A)

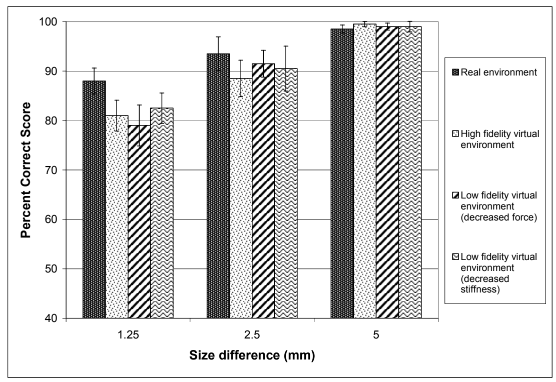

Figure 5. Results for all size discrimination experiments with round cross-section ridges (1B, 2B, 3B, and 4B)

although this result is not significant by the ANOVA. Overall, the two-way ANOVAs showed that there were no significant differences in performance when comparing based on environment (real, high fidelity virtual, low fidelity virtual-force, or low fidelity virtual-stiffness).

One subject commented that the low fidelity didn't feel much different than the high-fidelity. This comment supports the author's claim that low fidelity environments may be sufficient for some perceptual tasks.

5 Conclusions

The findings of these experiments, in which performance in a real environment was compared to performance in an environment displayed with a Phantom desktop for a size discrimination perception task, indicate that the Phantom does a fairly good job of approximating reality for the block environments described here. Not only do these results support the case that haptic interfaces are good at simulating real environments for these perceptual tasks, but they also show that they can do so without excessive machine performance demands. Results are similar to those found for other haptic interface hardware.

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